Timing is everything: Commentary on Managing Temporal Variables in Geographic Information Systems

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Introduction

At the 1991 CAA conference held at the University of Oxford, John Castleford presented a paper on time and GIS which was subsequently published in the proceedings as *"Archaeology, GIS, and the Time Dimension: An Overview"* (Castleford 1991). This work provided a much needed summation of the state of TGIS (Time and Geographic Information Systems) research and the archaeological concerns related to it.

Our paper is in part a follow-up to the Castleford paper, which is necessary because of advances that have occurred since then in TGIS research, computer technology in general, and in the archaeological and anthropological theories and conceptions of both space and time. It is also made necessary by the current lack of research and attention that the subject receives within the field of GIS and archaeology. In this paper we review both TGIS and "time" literature, discuss both the general and archaeological specifics involved with modelling and representing time in GIS, and propose suggestions for the future directions of TGIS research in archaeology.

The use of GIS in archaeology in 1991 was much different than it is today. There have been advances in both the complexity of GIS software and the conceptual design behind their application. In part, this can be related to vast increases in the capacity of both the hardware and the software that has occurred since then. Both the research capabilities and the practical solutions that GIS brings to the world of information technologies have expanded its base of interest to include many academic disciplines, large sectors of industry, and many facets of public administration. The net result of this has been a vast increase in the resources and attention being devoted to GIS research and development. This has led to a two-fold line of progress: both the infrastructure and the software has improved and, the general conceptual forces governing the creation and use of GIS has increased.

One important direction that has received attention (but perhaps not nearly as much as it requires) has been the treatment of time as an important component and variable. Geographic Information Systems always involve spatial variables (or as we will return to later, the capacity to deal with spatial variables). However, since many GIS applications analyse and study processes occurring in space (and processes are by nature not static) a temporal variable is of critical importance. The incorporation of temporal characteristics has been met with limited success depending mainly upon the specific nature of the characteristic and the role that time plays in the application. In the last ten years, focus on the "time problem" in GIS has produced various methods for incorporating time into representations. Much attention has been given to temporal data-bases and easily updatable GIS databases, although there has been less specific interest in the actual modelling of time. There are some examples of work done towards this end which will be discussed in the following section.

Time/Geographic Information Systems: Past Research

At the time of Castleford's paper there were several on-going research projects dealing with the specific issue of TGIS. Paramount amongst these was the work being done by Langran (1989, 1990, 1992) Langran and Chrismas (1988), Peuquet (1994) and Peuquet and Duan (1995). In addition to this, one of the research initiatives of the National Center for Geographic Information and Analysis centred at three universities in the United States was to facilitate research into time and geographic information systems (See Egenhofer and Golledge 1998 for the most recent output). From our present vantage, we are able to look at the final products of much of this work and the impact that it has upon the field. In the following sections we provide a brief summary of some of the main points stemming from this research.

A snapshot approach is a method that is based upon a sequential overlaying of spatially-registered grids. Each grid represents an area at a different point in time, sometimes referred to as a time slicing technique. Through a process of referring back to the previous state, a measure of the change that occurred at locations can be achieved based upon differences in pixel values. However, "the actual changes that occurred at locations between different points in time are not explicitly stored." (Peuquet and Duan 1995 p. 8) This is one of the problems of the model, that the processes of change are often concealed between the different presented stages. All that can be said with certainty from one stage to the next is what amount of change occurred. One can not see the how, when, why, and by whom of the issue using this model. A second major shortcoming is that each previous stage has to remain as a constant for the amount of change to be determined from the next overlaying stage. However, as demonstrated by Lock and Daly (this volume) this model, being a relatively simple raster based approach, can be run within existing GIS packages.

Langran (1992 p.46) has suggested a grid based approach that involves a "temporal grid with a variable-length list attached to each cell denoting successive changes..." This model is based upon representing each pixel in a grid of locations as a list containing temporal structure. The end result are cylinders standing vertically in each grid cell that use height and symbolic coding to represent locational change. This is a conceptual model and we are not aware of any specific applications of it.

Langran (1992) and others (Hazelton 1991), Hazelton et al. 1990), (Kemelis 1991) have proposed several models that are designed to show change through time as it is relative to specific entities rather than locations. In these models, changes are registered as incremental additions to an original feature. Its problems are similar to the snapshot method in that they just show additions and do not give much insight into the processes behind this change and also that they build upon an initial feature and neglect any aspects of change in the original feature other than what is additional. The original feature maintains its structural integrity throughout. This approach can be applied using most of the standard vector GIS packages including Arc/Info.

Rather than have a location of an object/feature based approach, Peuquet and Duan (1995) have proposed a time-based spatial data model called the Event-based Spatio Temporal Data Model or ESTDM for short. The basic premise is that change is temporally ordered to locations within an area. While this method seems to have some interesting potential, there are some obvious shortcomings attached to applying it within archaeology, not least that the type of temporal data it was designed for are instant specific. Basically, its temporal structure comes from a focused, specific ordering of events based upon an absolute temporal scale, which, as we all know, is difficult if not impossible to define with precision within the archaeological record. The second major drawback, and this is partially acknowledged in her work under the heading "potential ESTDM variations," (ibid, p. 21) is that the model is concerned with spatial change. She has suggested that there are possibilities for expanding it to include "non-spatial changes as they relate to geographic features."(ibid, p. 21) This could be an area of possible future interest in TGIS development.

Lin and Mark (1991) have discussed the potential of Spatio-Temporal Intersection (STIN) and volumetric modelling as measures for spatio-temporal correlation analysis. STIN is described by them as "an extension of the concept of 2D polygon overlay in existing GIS" (ibid, p. 4) and can be seen as a process of computing the intersection of two or more spatio-temporal volumetric units which generates a new spatio-temporal volumetric unit. The resulting spatio-temporal region represents information on changes for the selected data items, or the relations between or among the component spatial distributions during the time period being studied. The actual 3d intersection that occurs serves to define the common volume from two or more separate volumetric objects. To say this in a less technical fashion, the contents of two or more 3d spaces are analysed and a separate space is created to represent the change between them involving selected attributes and/or spatial distributions.

Lin and Mark (1991) also discuss some aspects of volumetric modelling, in particular generating a 3d temporal model from 2d raster data from multiple time periods. This is done through the process of "voxelization" (a voxel being a volumetric pixel) where 2d data sets are rasterized (if they are not originally in a raster format) and then converted into a 3d structure where the height of the voxels are dependant upon time intervals. From this point, a temporal interpolation can be used to construct temporal layers that fall between the original data based time slices. This, or course, brings with it the question of appropriate interpolation techniques.

In a paper on analysing change through time within an archaeological landscape, Lock and Harris (forthcoming) suggest a possible method, based upon 3d modelling capabilities, to display the "continuous temporal history of a spatial location" (which can be used as well for specific objects or features). This is done by operating within a 2d spatial frame of reference and using the third axis to represent a time line. The location or feature is represented as a column that varies in width according to the probability of that location (in this case a 'site') being in use at that time based upon various dating criteria. However, spatial characteristics, especially related to the third spatial dimension of elevation, are forfeited by the use of the temporal axis.

In spite of a moderate degree of attention that has been paid to the issue of time in geographic information systems, there has been remarkably little follow up and actual implementation of this work in a real context. This is not surprising however, when the following factors are considered. First, much of the research so far has been conceptual with scant few actual programs developed that can make the ideas usable in a practical sense. This is especially true within archaeological circles where there are both less computer resources and expertise.[1] Second, it is in some ways a problem for archaeologists and others who wish to study long term temporal processes that the main driving influences of the research are present day concerns. The bulk of the research on TGIS and in all other aspects of time in computer science focuses upon corporate, government, administrative, and military issues.

Being that the major impetus for the development of TGIS fall into the above categories, the nature and definitions of "time" are influenced by needs specific to the problems faced by these groups. The foundation for most TGIS research is a linear construction of time, typically based upon the standard grades of time using years, days, hours, seconds, etc. This can also be composed of a sequential ordering of events or an arbitrary set of numbers or symbols. Regardless of how the categories are defined, the research often presupposes that there will be a high degree of both quality and quantity control with regards to the data being used. Precision and standardised resolutions are desired, both of which are difficult, if not impossible, to obtain in archaeology in individual cases. It is not possible that archaeology as a

[1] This is, of course, a generalisation. But while acknowledging that there are archaeologists who possess the expertise and have access to the necessary infrastructure, it has to be stated that this is not the usual case.

discipline can arrive at a standardised definition of temporal scale based upon data of similar quantity and quality.

These are all agendas which do not create a lot of overlap for archaeologists to exploit thus putting archaeology in a situation where it has had to make use of techniques which are designed with other concerns in mind. In addition to this restricting the agency that archaeology has in the construction of the tools which it employs, it also means that most of the research being conducted by archaeologists using GIS (not just issues related to time) is done so within paradigms established by exterior influences. This has implications which will be addressed later in the paper.

Archaeological Treatment of Time

In his paper, Castleford suggested that "few archaeologists have addressed the wider issue of time." (Castleford 1991 p.96) The implication being that this was partly to blame for the lack of a strong research interest in issues related to time and geographic information systems in archaeology. While this might have been true at the time of his writing, there has been a sizeable corpus of literature published by archaeologists since then dealing with this wider issue of time. Much of this work draws upon concepts and philosophies of time as espoused by anthropologists (Evans-Pritchard 1939; Levi-Strauss 1948, 1961; Gell 1992; Bloch 1977; Fabian 1983; Bourdieu 1977), sociologists (Giddens 1984), geographers (Parkes and Thrift 1980; Carlstein et al 1975, 1978; and Hägerstrand 1975), and philosophers (Husserl 1966 [1887]; and Heidegger 1953). The body of research on temporal issues is wide and covers a broad spectrum of disciplines, each with their own unique perspective and agenda.

These studies have shown the varied and complex nature of time. Because of the enormity that the task of reviewing all of the literature would be, we will only touch upon the general ideas which are most relevant for expanding our interests.

Time is a force that exerts the dialectical relationship of ordering human activity while at the same time being partially defined by it. Many authors suggest that there are at least two broad categories of time: time as constituted by natural rhythms and patterns of activity and time as a constructed framework for ordering the temporal nature of activity (Gell 1992, Fabian 1983). In the former case, people respond to a tempo set by a natural force such as planetary motion or the diurnal cycles of light and darkness which constitute day and night. This can also be created by patterns of activity which subconsciously order peoples' lives such as harvest cycles, the migration of important animal resources, or ritual activity.

In more recent times, conscious control and manipulation of time has become an important factor as seen in all cultures which possess standardised mechanisms for regulating time such as calendars and clocks. This conscious ordering of time has become especially important with the modern age of industrialisation as the insistence on efficiency and the careful regulation of the modes and methods of production spawned more and more precise grades of time and techniques for measuring them.

There are distinct importances to each of these two categories. The first category comprises the substance of the temporal paradigms within which many "ethnographic" societies and certainly many prehistoric societies operated. The second structures the temporal frame of reference of the modern scientist, which is then used in the analysis of the "other" time. The understanding that we have of time is heavily reliant upon the structures which we are accustomed to although it is not impossible to conceive of and think about other temporal frames of reference. In fact, we are all subjected to the duality between time as experienced and time as measured and defined. This is a subtly which has not translated well into the world of computer science and may be potentially useful in all fields which deal with the study of human behaviour.

Archaeology, perhaps more than most disciplines, demands a different perspective and focus when it comes to temporal issues. Archaeologists deal with different durations, are largely limited to data of coarser resolution, and have to deal with temporal issues as they are related to and interpreted through the material culture of past peoples and societies. In works by Gosden (1994), Clark (1992), Thomas (1996), Barrett (1994) Bradley(1991; 1998), Ingold (1993), Terrell and Welsch (1997), Frachetti (1998), for example, specific attention is paid to how theoretical constructs of time can be relevant to and applied in archaeology. Also, attention is given to how archaeology can contribute to the overall understanding of time as it relates with humans and human processes.

There are many issues of time that the archaeologist has to consider. There is the basic temporal framework used for heuristic purposes by archaeologists to situate phenomena within an understandable and explainable scale of activity (with an emphasis on comparison as well). Past human activity is situated within spatial and temporal parameters established by the archaeologist, themselves within the standardised parameters of the research culture of the scientist, for example, the use of calendar years or a system of dating using years before present. The explanation and definition of cultures and activity often use blocked temporal spans or durations (i.e. categories that place the totality of an entire time/cultural period under one general label which serves to indicate many aspects, including time, of the period).

However, even at a very basic level, the current state of GIS research does not adequately provide for dealing with these heuristic frameworks used by archaeologists. The root of this problem is the basic inability to successfully incorporate temporal attributes in a meaningful and productive fashion which does not compromise the integrity of other aspects of the data or modelling process.

It is obvious that such analytical constructs, regardless of how well they can be modelled or integrated, are in no way reflective of the ways that past people, society, or culture situated and understood their activity. There are countless ways that people can experience and interact with space and time and we believe that there is definite potential within GIS to realise this and to, perhaps, provide a more empirical basis for its study. This line of thought has already taken root in archaeological GIS with work on viewsheds, movement through landscape, and other types of inquires into the experienced space of peoples (Wheatly 1993, 1995; Gillings 1998; and Llobera 1998). Zubrow (1994), suggests that GIS methodologies can be used to model and understand a range of cognitive processes. We suggest that similar approaches may be adopted for uncovering the temporal structures of a people; especially in cases where correlations can be drawn between the spatial and temporal characteristics of a people. Literature from the school of time geography suggests that this is quite possible (Carlstein et al 1978).

In an ultimate sense, there is a direct correlation between space and time with the speed of light being the theoretical ceiling on the possible transfer of information. However, until the very recent present, distance was a primary factor in determining temporality. In a modern context, the "time-space lifeworlds" proposed by time geographers suggest that there are sets of possible courses of actions that a person can embark upon based upon real world space and time constraints (Seamon 1980). There are both temporal constraints upon the spatial activities of people and spatial constraints upon the temporal scheduling of people.

We would like to suggest that while this might not be as relevant in terms of tracking the individual in time and space in prehistoric times (not because it does not apply, but rather that it is quite difficult to substantiate using archaeological evidence), the same general theories governing such temporal and spatial constraints can be extended to cultures and societies. In a specifically archaeological context, especially one in which there is a longer term duration being studied, it is quite possible that societies possessed temporal rhythms which are manifested in the spatial configuration of their activities. Following this line, evidence of long distance retinues such as complicated and spatially extensive networks of exchange and activity (including ritual activity), may give valuable hints at how a society is structured temporally. There are suggestions of this, for example, in some of Richard Bradley's work concerning votive deposits, the axe trade in Neolithic Britain, monuments in the landscape, and long term exchange networks and their temporal and spatial relationships (Bradley 1990; 1998) and (Bradley and Edmonds 1993).

Modelling and Representation

Temporal aspects within archaeology manifest themselves in a multitude of ways. In fact, it is impossible to discuss any aspect of archaeology with time not being of some consideration, even if it is indirect or implicit. It is clear that any GIS application within the field of archaeology has to have a temporal element and the success of the application will always be contingent upon how well the important variables, time being one of the most significant, are managed.

In addition to what has been mentioned above, there are a plethora of other issues which arise when dealing with time and GIS, firstly, the difference between modelling and representation. The representation of something is a static portrayal of its state at either a natural or arbitrary juncture, offering no value other than provided by the visual element. Of course, this is not to dismiss the great importance of visualisation. Representation is not in itself a process, it is the product of a process. Modelling, however, *is* based upon mathematical processes. In many ways, representations are taken from the modelling processes, either of the end result of the function, or of some determined interval point.

The distinction here is critical when comparing different GIS packages and techniques. In addition to the different algorithms which may be used (and thus the different processes to get to a similar end) there are fundamental differences between the mathematics of raster and vector systems. A raster system is one in which values are assigned by area and spaces within a gridded surface are given certain values and any function of these values is based upon principles of matrix algebra. A vector, by definition, is a function based upon rates and direction. Here we wish to emphasis that the processes of modelling within raster and vector systems are inherently different because of their underlying mathematical structure. This means that while representations may seem similar, they, in fact, actually depict images derived from different processes.

Models usually work under the assumption that there are either known beginning and/or end points. When they are comparative, they also assume some relationship between the sets of data bringing into question issues of definition in terms of the temporal parameters of case-studies and the theory and practice of being contemporary. The term *contemporary* becomes more suspect when removed from the insubstantial state of approximation and placed into the concrete world of the exact (which is often what occurs when modelling). To determine whether something is contemporary mathematically, one has to know the starting and ending points of that which is being compared and since this is rarely exact within archaeological data it is therefore usually impossible to exactly model simultaneity. While this exactness is never really expected within archaeological circles, it has to be noted because it could be a potential source of problems when modelling using a framework which is designed to precisely model such things. In this case, the model either will not be able to handle such data or the data will have to be altered so to fit the requirements of the model.

Data Sources and Implications

While there are many different sources of field based data which archaeologists incorporate into their studies, we feel that the main body of these fit into two general categories: surface and sub-surface. Both of these types of data are characterised by marked differences in collection and recording techniques, actual content and quality of material, and the possible analytical precision that the data will allow. As will be shown, data from these two types have to be managed in different ways in order to successfully incorporate them into an archaeological GIS. In addition, each of these types of data have different characteristics which impact the temporal modelling and representation options.

Surface data is any information which is collected from the surface of the ground, typically gathered using non-intrusive techniques. The most common examples are landscape surveys in which archaeological features are recognised and recorded (either by a direct visual approach or through some form of remote sensing) and more intensive surveys in which the distribution of cultural material upon the ground is recorded usually involving some form of sampling methodology. The key defining element which makes data "surface data" is that it has three real world dimensions (a location defined by an X and a Y and an elevation defined by the Z) but only two relative dimensions, i. e. it only has a horizontal position relative to the other data from the same set. There can be a high degree of mixing of cultural material and, in general, the material has been exposed to more post-depositional processes than buried material.

Sub-surface data are data which have three relative dimensions in addition to their real world positioning. Most of these data are derived from excavation (although there are some non-intrusive techniques which can be used to collect this type of data such as ground penetrating radar) and are situated within a 3d archaeological context where they can have both vertical and horizontal relationships with other data. It is usually from this type of data that samples suitable for absolute dating techniques such as radiocarbon dating are acquired.

There have been many methodologies constructed for managing these types of data. For surface data, there is a wide range of statistical techniques which have been employed to determine spatial relationships, while for sub-surface data, the stress is on the positioning of the data in-situ and relations are drawn from this. The most typical example of such techniques is the Harris Matrix (Harris 1979) in which relationships of sequence are drawn from the positioning of material and layers relative to each other. There are fundamental differences between the two in the way that temporally based relationships are determined. In surface surveys, there is often a known temporal scale to the material being studied where the types of cultural evidence are identified determining its main temporal range. The real interest of many such studies is the spatial extent of activity and types and amounts of activity occurring by periods represented. These data are also used to study longer term change within the landscape.

While certain that this is common knowledge to all after their first year of studying archaeology, we believe that the implications that it has for temporal modelling, both in a GIS and a wider context, are often neglected or taken for granted. This is especially the case when the potential of having a third dimension in a program is used for representing or modelling a temporal variable rather than the spatial one which was the original intent. This can be seen in the work of Harris and Lock (1996) where the spatial capabilities of the software are used to represent temporal values.

Suggestions and Commentary

There are several suggestions that we have for the "future" of TGIS in archaeology. The first involves the use of already existing and common packages and the second involves the possibilities offered by new technologies and avenues of research. There are many obvious restrictions that archaeologists have in relation to using GIS as a tool, not least that only a few packages are widely used because of the cost of purchasing and maintaining the infrastructure, and that there is a steep learning curve which accompanies GIS research. Because of these, there has to be a focus of research into how best to use these more common tools to model temporal processes. One emphasis that we would like to put forth is the importance of a pre-application conceptual model of how temporal variables have to be managed to give the desired result (see Lock and Daly this volume for an example)

There are three sources of potential for modelling and representing time within GIS which we feel are very promising. These are the use of Object Orientated GIS and databases, animation, and the Z axis. As discussed by Tschan (this volume), there is a great deal of potential for the use of Object Oriented GIS in archaeology which provides a different option to the more standard vector and raster packages. The flexibility in defining object relationships that OO GIS and databases provide has a tremendous potential for redefining how archaeologists can manage temporal variables. The possibility exists for unique temporal relationships to be constructed, unfettered by predetermined categories (for the basis of OO is the construction of the categories and the extents of the relationships that can exist between them). One of the main set backs with Object Orientation is that the packages are not in common use currently, and to exploit the full flexibility that OO offers, one has to possess a high degree of expertise in the operation and programming of the software.

Animation is a tool which is starting to be used in archaeological research to *show* processes. Animation can be valuable in representing dynamics, for example a paper by Nunez et al. (1997) which has simple but effective animated sequences showing the effects of isostatic uplift upon long term human activity in the Baltic basin. In addition to its capacity for showing sequences of activity occurring within a static geographic template, it has tremendous potential for being used in conjunction with Virtual Reality technologies. While animation is an interesting tool, it is restricted to the visualisation of processes and does not provide much in terms of analysis. Also, it is hardly compatible with the standard formats of publishing although an increase in CDROM and Internet based publications or supplements to hardcopy publications may make animation a more popular avenue in the near future.

The third source is in the use of the third dimension. At present GIS packages have the ability to model or represent two dimensional space/ two and a half dimensional space with the possibility for another if it is included as an attribute of the 2d space. There are some packages which give access to an analytically useful third spatial dimension. Volumetric modelling, mentioned by Lin and Mark (1991), has a great deal of potential and is broken up into voxel and continuous axis designs. Voxel techniques aggregate volumetric space into homogenous cubes which can have many uses, although it can be subjected to much of the same criticism that pixel based programs receive. With continuous axis programs it is possible to not just show uncompartmentalised 3d space but to also give value to that space. This type of software is typically used for the monitoring and exploitation of natural resources such as gas and petrol. There are also examples in which samples from cores are used to provide an interpolation of volumetric content and values of that space.

Different 3d technologies and their possible uses are discussed in detail in Raper (1989) and Harris and Lock (1996).

In theory this type of GIS can be of enormous importance to the modelling of sub-surface data enabling analysis without having to compromise its spatial integrity. Layers and contexts can be ordered spatially with their contents included as attributes, allowing for detailed GIS studies of excavation data which are not restricted to somehow compressing the data to fit a 2d or 2.5d scheme. It also allows for real world elements to be included in addition to any relative ones so that not only could data from different excavations be analysed in the same application, but it could also provide a venue for working with both surface and sub-surface data in the same package, i. e. for working with both 2d and 3d data without compromising either. The actualisation of these theoretical structures would be a major methodological breakthrough for synthesising discrete data sets from two distinct types of sources.

Conclusions

The use of GIS (and all other techniques) to define "culture" from material remains and spatial layout is inherently laden with theoretical implications. There are many ways in which this is done in archaeology, with cultures being defined by seriation, similarities in types, styles, materials, supposed temporal and spatial relationships, etc. All of these techniques are based upon the construction of categories by the archaeologist, ranging from the broad Stone Age to Iron Age categories to highly complicated and detailed gradations of pottery types. These issues have been raised elsewhere but we wish to draw particular attention to it within an archaeological GIS framework.

Usually GIS is a retrospective process for analysis whereby the material is collected, studied by specialists, and finally put into a database and subjected to GIS analysis. This means that in most cases, the information is already compartmentalised within categories and the GIS researcher then has to either use these categories or mould them as best as possible to fit into useful GIS parameters. The real issue then comes when a request to run a specific analysis is given because much of the analysis conducted within GIS involves the thresholding of information to give an indication of value, identity, change, and continuity. This is particularly evident in the case of landscape survey in which GIS is a common tool and, as noted above, the data are often mixed and it is the aim to determine the identity and nature of the activity occurring within the landscape. Thresholding is the basic technique used for this as discussed with a brief case-study by Lock and Daly (this volume).

While this might seem like a rather innocuous issue, it is, in our belief, one that is crucial to the understanding of issues concerning change and continuity within archaeology. GIS are becoming more and more widely used in archaeological projects to help determine such things and, with this, more and more power is invested in their use to actually define the categories used, and thus in a very real way, to define the structure of the data and their conversion into cultural sequences. The advancement of TGIS research in archaeology gives us yet another example of the ever growing role of GIS, not only in the implementation of archaeological theory, but in its development and construction.

Acknowledgements:

There are many people whose conversation, discussion, criticism, and suggestions have benefited this paper. We would like to thank: our colleagues from Oxford, Tyler Bell, Francesco Menotti, Marcos Llobera, and Andre Tschan for listening to and critiquing an early draft of this paper, Andre Tschan for his specific information on the use of Object Orientated GIS, Mark Gillings for several interesting discussions related

to the needs of TGIS research in archaeology, Chris Gosden for his comments on the theoretical issues of time, Ezra Zubrow for many useful ideas and suggestions, particularly concerning the technical end of modelling time, and J. Flasch . Both Sun Microsystems and Tadpole Technologies have provided invaluable technical support for this research.

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